MODELING OF BLOOD FLOW AND VESSEL MECHANICS IN THE CARDIOVASCULAR SYSTEM

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Introduction

Mathematical modeling is the application of mathematics to explain and predict real world behavior. It essentially consists of translating real world problems into mathematical problems, solving the mathematical problems and interpreting these solutions in the language of real world. The mathematical treatment of the problems by engineers have been traditionally regarded by physician as far removed from the pragmatic treatment of the disease, while the engineer has regarded the problem of physicians as empirical and non-scientific. A new multidisciplinary science is now arising which bridges the gap and draws upon both the life science and physical science for help and support. This area is 'biomechanics'. Biomechanics as an area, common to mechanics, physiology, medicine and even social and environmental studies is particularly difficult to define. Biomechanics is the application of mechanical principles on living organism. This includes research and analysis of the mechanics of living organism and the application of engineering principle to and from biological systems. The field of biomechanics seeks to develop physical laws combining the common properties of an idealized body in both static and dynamic sense.

Blood is the primary transport vehicle. It is a suspension of cells in an aqueous solution called "plasma". There are about $5*10^9$cells in a milliliter of human blood. About 5% of these cells are "platelets" which perform a function related to blood clotting. About 0.2% of the cells are 'white cells' which play a role in the resistance of the body to infection. Most of the cells in blood are 'red cells' the erythrocytes. The red cells make up about 45% of the blood volume in the average man (figure1). The volume fraction of red cells is known as the 'hematocrit' [1]. Plasma is composed of 90% water and about 7% protein. Among the major protein constituents of plasma are albumins and globulins which

maintain osmotic balance and thereby control the movement of water between blood and various tissues.

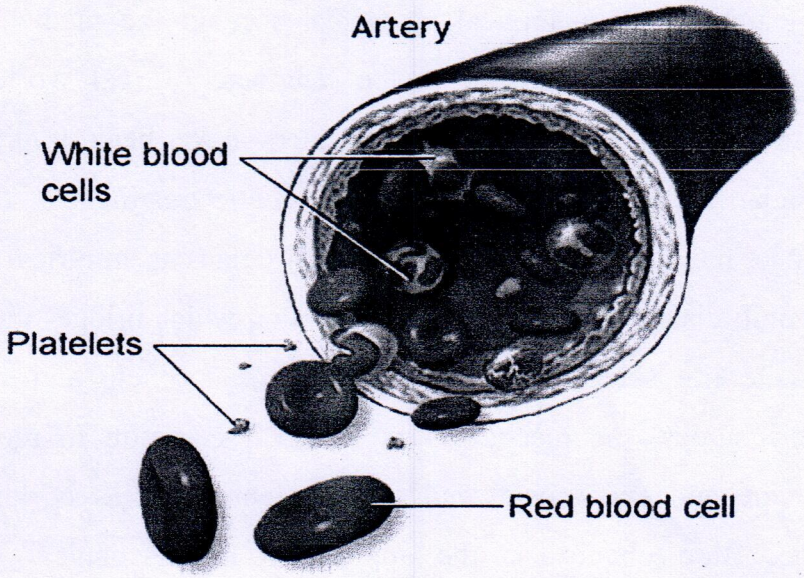

Figure 1: Composition of Blood in Artery

The functionally important constituent of blood is the red cell. Its primary role is the transportation of oxygen from the lungs to all the cells of the body and the removal of carbon dioxide formed by metabolic processes. Blood flow is the continuous circulation of blood in the cardiovascular system. Blood flow is essential as it carries oxygen and nutrients to body's tissues and carbon dioxide and waste products away from the tissues. It is also needed to sustain life and promote the health of all the body's tissues. Science dedicated to study physics of blood flow is called hemodynamics. It is important to study blood flow to understand the connection between flow characteristics and the development cardiovascular diseases.

The heart is the pump responsible for maintaining adequate circulation of oxygenated blood around the vascular network of the body. It is a four-chamber pump, with the right side receiving deoxygenated blood from the body at low pressure and pumping it to the lungs (the pulmonary circulation) and the left side receiving oxygenated blood from the lungs and pumping it at high pressure around the body (the systemic circulation). The myocardium (cardiac muscle) is a specialized form of muscle, consisting of individual cells joined by electrical connections. The contraction of each cell is produced by a rise in intracellular calcium concentration leading to spontaneous depolarization, and as each cell is electrically connected to its neighbor, contraction of one cell leads to a wave of depolarization and contraction across the myocardium. There are three major types of blood vessels: arteries, capillaries and veins.

- **Arteries**: Arteries are blood vessels that carry blood away from the heart. Blood carried by arteries is usually highly oxygenated, having just left the lungs on its way to the body's tissues. Arteries face high levels of blood pressure as they carry blood being pushed from the heart under great force. To withstand this pressure, the walls of the arteries are thicker, more elastic, and more muscular than those of other vessels.
- **Capillaries**: Capillaries are the smallest and thinnest of the blood vessels in the body and also the most common. They can be found running throughout almost every tissue of the body and border the edges of the body's avascular tissues. Capillaries carry blood very close to the cells of the tissues of the body in order to exchange gases, nutrients, and waste products. The walls of capillaries consist of only a thin layer of endothelium so that there is the minimum amount of structure possible between the blood and the tissues.
- **Veins**: Veins are the large return vessels of the body and act as the blood return counterparts of arteries. Because the arteries, arterioles, and capillaries absorb most

of the force of the heart's contractions, veins and venules are subjected to very low blood pressures. This lack of pressure allows the walls of veins to be much thinner, less elastic, and less muscular than the walls of arteries.

Systemic arteries:

- Large arteries (cm)
- Small arteries (mm)
- Arterioles (100 μ)
- Capilaries (50 μ)

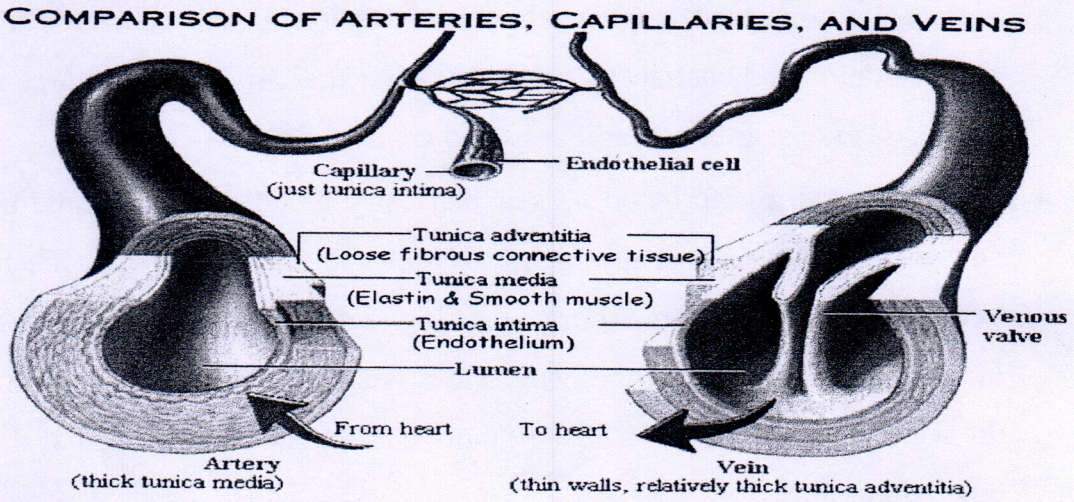

Figure 2: Comparison of Arteries, Capillaries and Veins

Blood acts as non-Newtonian fluid at low shear stress but at higher shear stress it acts as Newtonian fluid. Blood vessels are the body's highways that allow blood to flow quickly and efficiently from the heart to every region of the body and back again. The size of blood vessels corresponds with the amount of blood that passes through the vessel. All blood vessels contain a hollow area called the lumen through which blood is able to flow. Around the lumen is the wall of the vessel, which may be thin in the case of capillaries or very thick in the case of arteries. The task of maintaining an adequate interstitial homeostasis (the proper nutritional

environment surrounding all cells in your body) requires that blood flows almost continuously through each of the millions of capillaries in the body.

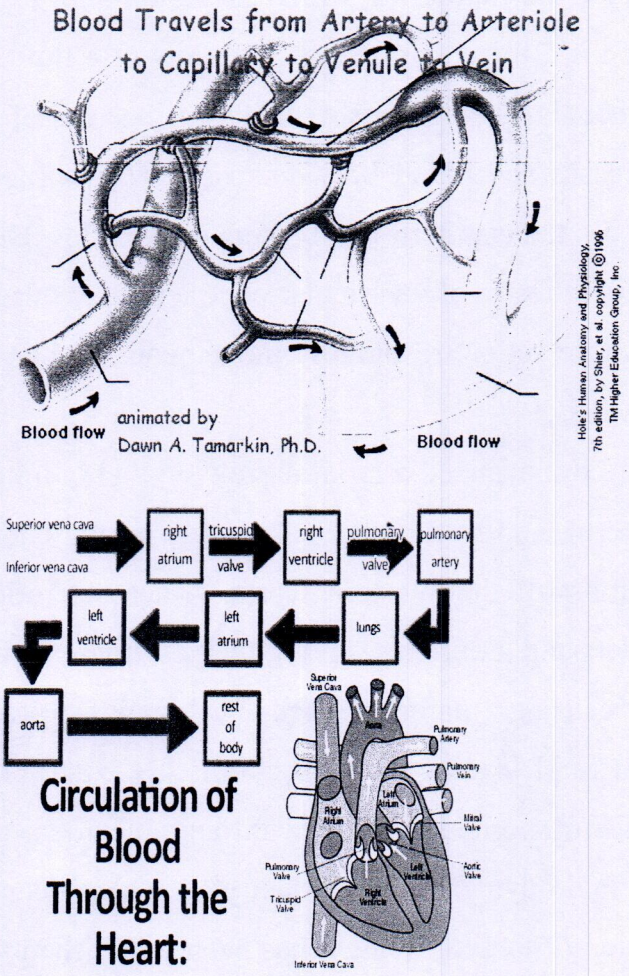

Figure 3: Circulation of Blood

The velocity of blood flow varies inversely with the total cross-sectional area of the blood vessels. As the total cross-sectional area of the vessels increases, the velocity of flow decreases. In normal condition, blood flow has laminar characteristics and that's why blood is maximum in the middle of the vessel and slowest at the wall of the vessel. Blood velocities in arteries are higher during systole than during

diastole. Blood flow is slowest in the capillaries, which allows time for exchange of gases and nutrients. Resistance is a force that opposes the flow of a fluid. In blood vessels, most of the resistance is due to vessel diameter. As vessel diameter decreases, the resistance increases and blood flow decreases. Very little pressure remains by the time blood leaves the capillaries and enters the venules. Blood flow through the veins is not the direct result of ventricular contraction. Instead, venous return depends on skeletal muscle action, respiratory movements, and constriction of smooth muscle in venous walls.

Stenosis is characterized by localized arterial narrowing that is initiated due to deposition of lipid, cholesterol, and some other substances on the endothelium and is of major concern to most of the Western world. Atherosclerotic lesions preferentially occur in arteries and arterioles in regions of high curvature or bifurcations and junctions causing major changes in flow structure and consequently large changes in fluid loading on vessel walls [2]. Such plaques or arterial constrictions usually disturb normal blood flow through the artery and there is considerable evidence that hydrodynamic factors can play a significant role in the development and progression of these lesions. It has been established that once a mild stenosis is developed inside the arterial lumen, the resulting flow disorder further influences the development of the disease and the arterial deformability to some extent, which eventually changes the regional blood rheology as well [3]. Atherosclerostic stenosis develops in three stages: initial stage when thickening of arteries starts, the growth stage, and the final stage when stenosis becomes severe enough so that the artery becomes constricted. Fig.4 below shows buildup of stenosis in arteries.

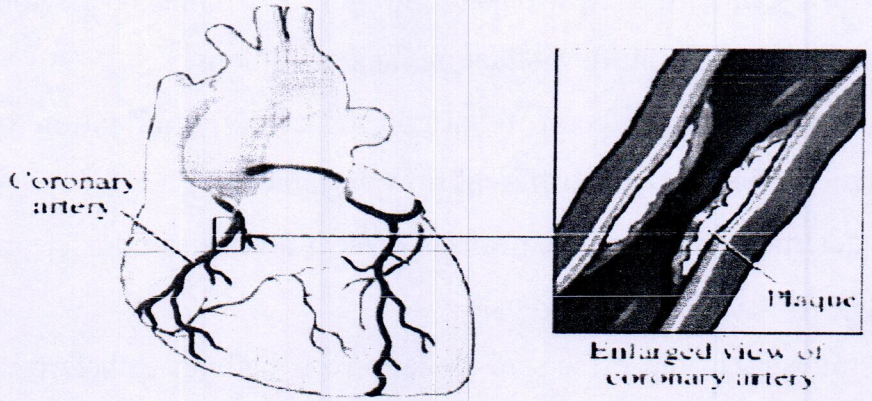

Figure 4: Blockage in Coronary Artery Restricts Blood Flow to the Heart

Flow of blood through stenosed arteries is quite different from that of normal arteries. Stresses and resistance to blood flow are higher in stenosed arteries. Stenosis leads to high blood flow speeds, leading to considerable compressive stress in the tube wall and critical flow conditions such as negative pressure, high shear stress and flow separation. These flow conditions causes artery fatigue, arterial compression flow limitations and possible flow induced instabilities.

Aims of the study

This thesis focuses on the study of the modeling of blood flow and vessel mechanics in the cardiovascular system. The aim of the thesis is to investigate the behaviour of blood flow through the different geometries of artery with and without stenosis. The influence of Newtonian and non-Newtonian behaviour of blood, steady nature on the stenotic flow field and other flow parameters, are examined. A theoretical investigation is carried out for analyzing the role of different flow parameters involved. The objectives of the thesis have included the following:

- To investigate the Newtonian and non-Newtonian behaviour of blood flow considering different flow situations and conditions.
- To examine the effects of variable viscosity, inclination of artery, applied magnetic fields etc. on different flow variables.
- To determine the combined effects of heat and mass transfer on blood flow in an artery with and without stenosis.
- To investigate the effects of radiation on balloon catheterized arterial stenosis when blood is represented by MHD Newtonian fluid.
- To examine the effects of Soret-Dufour, radiation and chemical reaction on MHD blood flow through a stenosed artery.
- To perform computational work and graphical presentation to include the flow of blood both quantitatively and qualitatively, subject to various flow parameters.

Review of literature:

Flow of blood through arteries is an important physiological problem, and is of considerable interest for biomedical researchers, physiologists, and clinicians. The study of bio-fluids under the presence of magnetic field with dissipation finds its applications in various upcoming fields like innovative drug targeting, surgical operations etc. Various surgical operations require significant control of the fluid flow and heat transfer of biological fluids. The presence of electromagnetic fields during such operations can have impacts on the human circulation system. The electric nature of bio-fluid like blood is already confirmed from previous studies. The presence of iron oxides in the hemoglobin molecule has been shown by Takeuchi *et al.* [4] to produce strong magnetic properties in blood. Under oxygenated conditions blood exhibits diamagnetic properties and under

deoxygenated conditions it behaves as a paramagnetic fluid. The presence of a porous medium during the flow presents a more physically realizable study. This approach can be modeled in the blood vessels and pulmonary systems due to the presence of fatty deposits and artery blockages. Generally, a Darcy model is most widely used for modeling the porous conditions but under higher pressure gradients and in highly porous regimes where inertial effects dominate viscous effects, the Darcian model flow is inadequate. Khaled and Vafai [5] have presented a rigorous review of heat and fluid dynamics applications in porous (biological) media. Recently, the effects of temporally varying wall mass flux on hydromagnetic pulsatile Newtonian blood flow in a Darcian porous model of the cardiovascular system, using a regular perturbation technique investigated by Ogulu and Amos [6]. The popular approach to simulate drag forces experienced at higher velocities employs the Forchheimer extension to Darcian model and thus known as Darcy-Forchheimer drag model. Various studies using this model have been presented in the context of porous media heat transfer, as described by Pop and Ingham [7]. Significant works include those by Preziosi and Farina [8] who studied mass exchange using an extended Darcy model.

Most studies have ignored the simultaneous diffusion of heat in the blood flow. Initial interest in pulsatile heat transfer flows emerged in mechanical and industrial thermal engineering systems where many studies have been reported again mainly for Newtonian fluids. Chao and Hyun [9] later studied computationally the pulsatile heat transfer in a pipe showing that in the downstream fully-established domain, the Nusselt number either increases or decreases over the steady-flow value. It may be mentioned that blood flow enhances when a man performs hard physical work and also when the body is exposed to excessive heat environment. In such cases, blood circulation can not be remain normal. In order to take care of the increase in blood flow, the dimensions of the artery have to

increase suitably. Several studies have addressed the pulsatile blood flows with heat transfer. Makinde and Makasu [10] studied pulsating blood flow with heat transfer in a conduit with gradually-varying cross-section. Craciunescu and Clegg [11] considered periodic blood flow effects on heat transfer in rigid vessels. Majee and Shit [12] numerically studied heat transfer in an unsteady flow of blood with the main objective to characterize the dynamics of blood through arteries with stenotic affections. It is known that when the temperature of the surroundings exceeds 20^0C, heat transfer takes place from the surface of the skin by the process of evaporation through sweating and when the temperature is below 20^0C, the human body loses heat by conduction and radiation both. Thus, human body is a thermal system. It generates heat by various biochemical reactions at cellular level and maintains its temperature within a short-range using various thermoregulatory mechanisms. The overall thermal behavior of the human body is the combined effect of heat generation and heat transfer at various scales, viz., microscale (molecular or cellular level), mesoscale (tissue and organ level) and macroscale (thermal interaction of the complete body with environment). Understanding the thermal behavior at these length scales is essential in many applications that include therapeutic, diagnosis, bio- chemical, thermal, environmental and preservation sciences. Tzirtzilakis and Tanoudis [13] and Louckopoulos and Tzirtzilakis [14] have reported on heat transfer in bio-magneto fluid flows for bio-magnetic convective heat transfer over a stretching surface and in a parallel-plate system. Radiation effect in blood flow is an important subject of research, because it has got significant applications in biomedical engineering and several medical treatment methods, particularly in thermal therapeutic procedures. Several experimental investigations have been carried out by Kobu [15], Inoue and Kabaya [16] and Nishimoto *et al.* [17] to examine the effects of infrared radiation/ultrasonic radiation on blood flow. Infrared radiation is one of the

frequently used techniques for making heat treatment to various parts of the human body. This technique is preferred in heat therapy, because by using infrared radiation it is possible to directly heat the blood capillaries of the affected areas of the body. In the treatment of muscle spasm, myalgia (muscle pain), chronic wide-spreed pain (fibromyalgia, in medical terms) and permanent shortening of muscle (medically called as contracture), heat therapy is found to be very effective. Recently, following the idea by Chintoya and Makinde [18], Tabi et al. [19] showed that the interplay between heat and magnetic effect may be efficient in controlling the velocity and temperature distribution during thermal radiation therapy. A true explanation to this is linked to the fact that blood is a biomagnetic fluid due to the strong presence of erythrocytes in its constitution. Erythrocytes, or red blood cells, are in fact negative charge carriers and this creates a magnetic field on the vessel wall, capable of influencing the pulsatile character of the blood flowing inside the vessel. There are many important technological problems that concern the flow of chemically-reacting fluid mixtures. Many biological fluid systems are examples of such mixtures. For example, blood is a complex mixture of plasma, proteins, cells, and a variety of other chemicals that is modeled usually in a homogenized sense as a single constituent fluid. Blood is maintained in a delicate balance by a variety of chemical reactions, some that aid its coagulation and others its dissolution. Complicated models have been proposed to describe the biochemical reactions and the complex interplay between the rheology and biochemistry of flowing blood by Kuharsky and Fogelson [20]. It is well-known that a viscous fluid normally sticks to the boundary, that is, there is no slip of the fluid relative to the boundary. There are, however, many situations where may be a partial slip between the fluid and the boundary. For many fluids, such as particulate fluids, the motion is still governed by the Navier–Stokes equations, but the usual no-slip condition at the boundary should be replaced by the

slip condition [21]. Nubar[22] and Brunn[23] suggested the presence of a red blood cell slip at the vessel wall. In view of the possible presence of a red blood cell (erythrocyte) slip at the wall, they considered a slip velocity at the wall in their study.

In experimental and clinical settings, many physiologic factors affect cerebral blood flow velocity. Among them, hematocrit and core temperature have been widely studied. In adults, normovolaemic haemodilution with a decrease of hematocrit from 38% to 30% was associated with an average 16% increase in cerebral blood flow velocity [24]. The effects of hematocrit and temperature on cerebral blood flow velocity can be related either to their effect on blood viscosity, on cerebral blood flow adaptation to cerebral metabolic rate for oxygen, or both. Changes in hematocrit can change blood viscosity. Blood viscosity increases when blood temperature decreases. Blood viscosity increases by 50% to 300% as temperature is decreased from 37°C to 22°C [25-26]. Often, even lower blood temperatures, in the range of 8°C–12°C, are typically encountered when performing deliberate deep hypothermia for cardiac or thoracic aortic operations requiring temporary circulatory arrest [27-28]. Shit and Majee [29] showed that the competition between applied magnetic field and body vibration may have strong health implications in the axial wave profile, temperature and flow rate in the presence of variable viscosity. Because the physical characteristics of blood are complex, blood's rheological properties at temperatures commonly used for deep hypothermia cannot be reliably predicted based on measurements performed at higher temperatures.

With the evolution of coronary balloon angioplasty in modern time, it has been a considerable increase in the use of catheters of different sizes. Catheters are medical devices and by revising the material or adjusting the way catheters are manufactured, it can be inserted in the body to treat diseases or perform a surgical

procedure. Also, it is possible to fit catheters in various situations like; cardiovascular, gastrointestinal, urological, neurovascular and ophthalmic applications. Catheters can be inserted into a body duct, cavity or vessel. The process of inserting a catheter in the body is called catheterization. It is observed by many researchers that insertion of a catheter into the lumen of the stenosed artery consequences substantial deviations in the blood flow pattern. Applying this fact, Mekheimer and Kot [30] discussed the effects of tapering in arterial wall with stenosis and catheter size on blood flow. Recently, under pathological conditions, the blood flow through catheterized artery was theoretically addressed by Mekheiner and Kot [31].

Methodology

The governing equations of motion (Navier-Stokes equations) are highly non-linear. The class of flows, which admits exact analytical solutions of these Navier-Stokes equations, is extremely narrow. Hence one has to fall back upon either a numerical solution or an approximate analytical solution. Even if one is able to obtain an exact analytical solution, it is likely to be extremely complicated. Hence it seems highly desirable and natural to seek numerical and approximate solutions of the flow problems. Hence, to solve these equations, various types of numerical semi-analytic and methods have been designed. Among numerical methods, finite difference method (FDM), will be used. The usage of such technique is easier, handy and most importantly accurate due to availability of high speed computers and commercially available state of art softwares. To obtain the difference equations in FDM, the region of the flow will be divided into a gird or mesh of lines. The number of grids depends on the distance of the flow boundary. Solutions of difference equations will be obtained at the intersection of these mesh lines

called nodes. The finite-difference equations at every internal nodal point on a particular n-level constitute a tri-diagonal system of equations. An iterative scheme will be used to solve the linearized system of difference equations. The solution at a certain time step will be chosen as an initial guess for next time step and iterations will be continued till convergence, within a prescribed accuracy. The results will be represented graphically/tabulated to make comparative study. The effect of various parameters on the flow pattern of velocity, temperature and concentration distribution along with that of shearing stress, rate of heat transfer and rate of mass transfer will be examined to draw physical interpretations from the numerical results which are of great importance to scientist and engineers.

Findings and concluding remarks:

In the thesis, some mathematical models of blood flow with and without stenosis in an artery have been studied. In the analysis, body fluid blood is assumed to behave as Newtonian and non-Newtonian fluids. Numerical results are obtained by using "MATLAB". Results are interpreted and represented graphically. The complete work is divided into seven chapters including the ongoing chapter on general introduction where fundamental concepts along with the review of related literatures are given. The references cited in the literature are compiled at the end. The chapter wise organization of the thesis is as follows:

CHAPTER-1

This chapter describes general introduction and gives a brief account for blood vessels, arterial system, arterial diseases, stenosis, cardiovascular system, characteristics of blood, magneto-hydrodynamics, porous medium and periodic body acceleration etc. At the end of the chapter, summary of the whole work embodied in the thesis is given.

CHAPTER-2

Mathematical modeling of magneto pulsatile blood flow through a porous medium with heat source

In this chapter, a mathematical model for the hydromagnetic blood flow in the non-Darcy porous medium with a heat source and Joule effect is proposed. A uniform magnetic field acts perpendicular to the porous surface. The governing non-linear partial differential equations have been solved numerically by applying the explicit finite difference Method (FDM). The effects of various parameters such as the Reynolds number, hydro-magnetic parameter, Forchheimer parameter, Darcian parameter, Prandtl number, Eckert number, heat source parameter, Schmidt number on the velocity, temperature and concentration have been examined with the help of graphs. The present study finds its applications in surgical operations, industrial material processing and various heat transfer operations.

CHAPTER-3

Thermal radiation effect on inclined arterial blood flow through a non-Darcian porous medium with magnetic field

Chapter 3 deals with the hydro-magnetic inclined arterial blood flow through a non-Darcy porous medium with thermal radiation. A uniform magnetic field is applied to the inclined porous surface. The dimensionless governing coupled, non-linear partial differential equations are solved by an efficient, accurate and extensively validated finite difference scheme. The effects of the various important parameters entering into the problem like thermal radiation, Reynolds number, hydro-magnetic parameter, Forchheimer parameter, Darcian parameter, Prandtl number, inclined angle and variable viscosity parameter on the velocity and temperature have been examined with the help of graphs.

CHAPTER-4

Effect of variable viscosity on chemically reacting magneto-blood flow with heat and mass transfer

In this chapter a theoretical analysis is presented for pulsatile bio-magnetic MHD blood flow with heat and mass transfer in the presence of variable viscosity. A uniform magnetic field is applied perpendicular to the porous surface. A mathematical model is developed and analyzed by using appropriate mathematical techniques. The dimensionless governing coupled, non-linear partial differential equations are solved numerically. The effects of various parameters like Reynolds number, hydro-magnetic parameter, variable viscosity parameter, Chemical reaction parameter, Schmidt number and Prandtl number on the velocity, temperature and concentration have been examined with the help of graphs. The present results reported here are likely to have an important bearing on the therapeutic procedure of hyperthermia, particularly in understanding/regulating blood flow and heat transfer in capillaries.

CHAPTER-5

Radiation effect on MHD blood flow through a tapered porous stenosed artery with thermal and mass diffusion

A mathematical model for MHD blood flow through a stenosed artery in the presence of thermal radiation has been studied in this chapter. A uniform magnetic field is applied perpendicular to the porous surface. The governing non-linear partial differential equations have been transformed in to linear partial differential equations, which are solved numerically by applying explicit finite difference method. The numerical results are presented graphically in the form of velocity, temperature and concentration profiles. The effects of various parameters like

Reynolds number, Hartmann number, radiation parameter, Schmidt number and Prandtl number, Soret and Dufour parameter on the velocity, temperature and concentration have been examined with the help of graphs. The present results have an important bearing on the therapeutic procedure of hyperthermia, particularly in understanding/regulating blood flow and heat transfer in capillaries.

CHAPTER-6

Modeling of MHD blood flow in a balloon catheterized arterial stenosis with thermal radiation

This chapter is concerned with the analysis of blood flow through arterial catheterization (widening of arteries by a balloon in the presence of mild stenosis), when blood is represented by MHD Newtonian fluid. The mild stenosis approximation is used to solve the problem. A uniform magnetic field is applied perpendicular to the porous artery. A mathematical model is developed and analyzed by using appropriate mathematical techniques. The dimensionless governing coupled, non-linear partial differential equations are solved numerically by finite difference method. This study provides a scope for estimating the influence of the problem parameters on different flow characteristics and to determine which of the parameters has the most dominating role. The study of the above model is very significant as it has direct applications in the treatment of cardiovascular diseases.

CHAPTER-7

Soret and Dufour effects on MHD mixed convection blood flow through a stenosed artery with thermal radiation and chemical reaction

This chapter explains the effects of Soret-Dufour on MHD mixed convection blood flow of a viscous incompressible electrically conducting fluid through a stenosed artery. The influences of heat and chemical reactions on blood flow are also taken into account. The non-dimensional forms of governing equations of flow have been solved numerically using finite difference method. The effects of different physical parameters on velocity, temperature and concentration profiles are discussed graphically. This analysis may provide a good understanding about blood flow in a diseased blood vessel and also useful under various pathological situation. The present results agree with some of the existing outcomes in the literature. The results obtained from the study can be used in regularizing the values of the model parameters and hence can be used for medical applications.

Summary of the work carried out in this theoretical investigation that includes different blood flow models, under different flow situations and conditions and, their possible improvement and, scope of further and future study, has been included at the end.

Signifiance of Works :

- The present work will be suitable for the application to the hydrodynamical flow of blood in a coronary artery when it is subjected to the influence of an externally applied magnetic field. The magnetic response of blood involves paramagnetic contribution emerging from the iron content of hemoglobin molecules and the

diamagnetic contribution emerging from hydrogen, oxygen, nitrogen and carbon atoms contained in vessel tissues. The red blood cell (erythrocyte) is a major biomagnetic substance and therefore, it is quite possible that blood flow will be influenced by the presence of an external magnetic field. The study will also find applications in surgical operations, where it is necessary to reduce the blood flow rate.

- It is known that heat transfer takes place in various tissues of humans. This is associated with various processes, e.g., heat conduction in tissues and heat transfer caused by the perfusion of the arterial-venous blood through the pores of porous matrix of the tissue (usually referred to as blood convection). Because of the consideration of coupled temperature effects, the mathematical models in the study bear the potential to explore various changes in arterial blood flow characteristics during the therapeutic procedure of electromagnetic hyperthermia.
- In addition to the aforementioned usefulness of heat transfer in blood vessels, the radiation effect in blood is of significant interest to clinicians in the therapeutic procedure of hyperthermia, which has a well-recognized effect in oncology. The present work will be motivated towards studying the flow and heat transfer in capillary blood vessels bear the promise of useful applications in clinical sciences, particularly in thermal therapy. It will also bear the potential of significant applications in different problems of biomedical engineering.
- Further, the study will be useful in assessing the accuracy of future experimental/theoretical studies of more complex nature, that may involve greater number of physical parameters.
- The study serves as a first step towards exploring blood flow in a pathological situation, when fatty plaques of cholesterol are formed and/or when artery-clogging takes place in the lumen of an artery. The study is also useful in investigating blood flow in and around a region, where a tumor has been formed. Clinicians dealing

with treatment of various hemodynamical diseases by the application of an external magnetic field will also find the results interesting. Moreover, the results of the present study will be of immense benefit in validating the results of similar experimental studies and those of more complex theoretical studies to be carried out in future.

- The results of the study bear the promise of applications to the flow of a variety of industrial and physiological fluids. It can also be applied to explore important information of many bioengineering problems, where the flexible surfaces of the biological conduits in living systems are in a state of stretching motion and are subject to the action of an external magnetic field. The present study will also be useful in validating the results of future investigations of more complex problems related to the behaviour of ionic liquids and biomolecules.

Future Prospects :

The present study is of particular interest to biophysicists, physiologists and clinicians, because blood flow circulation time is considerably changed after certain classes of drugs are injected into the body. Rate of chemical reaction can also be increased by increasing blood flow. Also, blood flow affects all catabolic reactions and in vertebrates enzyme reaction rate is controlled mainly by adjusting the rate of blood flow by some appropriate means. Finally, we can conclude that further potential improvements of the model are anticipated.

- Since the hematocrit positively affects blood pressure, further study should examine the other factors such as diet, tobacco, smoking, overweight etc. from a cardiovascular point of view.
- In the most of studies, the fluid viscosity is assumed to be constant. This assumption is not valid everywhere. Whole blood viscosity is mainly determined

by hematocrit and temperature, whereas plasma viscosity mainly depends on the concentration of high molecular weight proteins In general, the coefficient of viscosity for real fluids are functions of temperature and pressure. Therefore, it is highly desirable to include the effect of temperature-dependent viscosity and variable hematocrit in momentum and thermal transport processes.

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